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Beneath the Waves and Beyond the Screen: Visualising subsea survey data in three dimensions

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High-resolution subsea survey data offers a new ability to explore difficult or hazardous environments, and using multi-beam sonar, provides three-dimensional bathymetric data for visualisation. However, this data represents three-dimensional structures and locations that exist in physical space, and yet we commonly limit ourselves to viewing them in a static and two-dimensional screen-based format. Are we getting the most out of this data? Are computers, the very devices that have enabled us to “see” these objects, limiting our ability to interact with and interrogate the rich data being gathered? The author has conducted a series of workshops focused on evaluating the ‘data lifecycle’, in an attempt to improve our understanding of the communicative value of different visualisation techniques. By exploring methods of visualising subsea survey data in new, interesting, and challenging ways we can improve our understanding of the underlying data, challenge our preconceived ideas on what it might be telling us, and encourage interactivity in ways that simply wasn’t possible before.

Data visualisation. 3D computer graphics. Tangible data. Creative practice. Visual perception.

1 INTRODUCTION

Deep beneath the ocean’s surface exists a world rich in wonder and fascination - a world that, unfortunately, most of us will never see.

By using the latest in acoustical imaging technology, expert surveyors are now able to gather better data than ever before about these underwater environments, and the objects and structures that they may contain - offering us new insight into these exciting and previously unseen worlds.

Through the development of advanced computing techniques, visualisation continues “making the invisible visible” (Cox, 2006), offering new opportunities for presenting data in ways that are both understandable and exciting, and which use innovative new types of output media to improve interactivity and levels of engagement.

As part of ongoing doctoral research, the author is working collaboratively with experts in art and design, visualisation and surveying to explore how subsea survey data is being communicated, and how this can be improved.

The first part of this paper will provide some context and introduce the tools and methods currently used

in visualising subsea survey data, before looking ‘beyond the screen’ at the increasing relevance of tangible data. The second part will focus on a case study detailing the creation, delivery and results of an interactive workshop, exploring the lifecycle of a single dataset throughout this visualisation process. Finally, as this research forms part of ongoing creative practice, reflection on both the workshop and visualisation process will be provided, summarising key points uncovered, and identifying critical areas of future development.

2 BENEATH THE WAVES

SOund Navigation And Ranging (SONAR) is a type of acoustical imaging used to gather information about objects and locations underwater. SONAR can be used to “develop nautical charts, locate underwater hazards to navigation, search for and map objects on the sea floor such as shipwrecks, and map the sea floor itself” (NOAA, 2014).

This subsea survey data, also known as bathymetric data, is commonly collected using a multi-beam echo sounder (MBES) – a SONAR device that uses a large number of beams to create a wider ‘swath’ of soundings covering a larger survey footprint than a single-beam echo sounder. Multi-beam sonar

systems generate data that typically uses a Cartesian coordinate system (X, Y, and Z, where Z is vertical depth). This data (initially in text format) can be viewed as a series of points in three-dimensional space, creating a 'point cloud' (or virtual representation), which can be moved, rotated, explored and measured.

Although there are different types of SONAR available, such as side-scan or synthetic aperture, the author's research is focused on surveys completed using multi-beam sonar, as this provides three-dimensional data, and is regularly used by the industry collaborator and part-funder ADUS DeepOcean (who specialise in undertaking high-resolution subsea surveys).

The use of sonar data often provides significant new knowledge that can be essential in making decisions, as is often more visible during any particularly high-profile incidents. For example, ADUS DeepOcean conducted multiple surveys of the Costa Concordia (an Italian cruise ship which capsized and sank in January 2012), supplying a combination of sonar and laser data. This proved invaluable in enabling better-educated engineering decisions, such as planning for the parbuckling (rotating upright) of the damaged vessel (ADUS DeepOcean, 2013). Although the parbuckling process itself was complex, the surveying process was much simpler in comparison, with the results enabling a higher degree of informed decision-making.

In contrast, the search for Malaysian Airlines Flight 370 – an international passenger flight which disappeared in March 2014 – has proven much more difficult. With the initial search and rescue attempts yielding no results, a larger-scale bathymetric survey of the area was commissioned. Around one year later, and having searched "more than 26,000 square kilometres of the seafloor" (more than 40% of the priority area), the Australian Government's Joint Agency Coordination Centre (JACC) reports that although they have found a number of low-interest objects (likely to be shipping containers), there have been no high-interest sonar contacts (JACC, 2015). In this instance, a high resolution search and mapping of the seabed may not yet have found the missing flight, but has proven invaluable in improving our knowledge of the 'deep ocean' – of which around 95% remains unmapped (Campbell, 2014).

However, despite being able to use sonar data to safely explore difficult or hazardous environments, the data is of no real use in its purest, raw form – simply having or acquiring data is not enough, it must be processed and visualised before it becomes useful and can gain meaning.

3 VISUALISING SUBSEA SURVEY DATA

Data visualisation is typically described as the representation of data (often numerical) using visual methods, and is generally created from raw, unprocessed and uninterpreted source material. More specifically, Tufte (2001) describes the results of using these visual methods as data graphics, which show "measured quantities by means of the combined use of points, lines, a coordinate system, numbers, symbols, words, shading, and color". It is important to note that although data visualisation has a focus on improving the presentation of data, it is also about extracting meaning, which should not be at the expense of the accuracy and truth of the underlying data source being visualised.

Although the goal of data visualisation varies across disciplines, in its simplest form, Few (2013) describes data visualisation as having two main purposes - "sense-making ... and communication". This notion of improving communication is reinforced by Kosara (2008), who states that "data must come from something that is abstract or at least not immediately visible", and requires some degree of transformation to enable a clearer explanation of the underlying content.

With Tufte (2001) believing that "graphics *reveal* data", Friedman (2007) develops this idea, telling us that "to convey a message to your readers effectively, sometimes you need more than just a simple pie chart of your results". Current visualisation practitioners share this viewpoint and continue to develop innovative new ways of presenting data, believing that the communication of complex data can be improved by using new visual methods, which also allow for a greater amount of information to be understood more efficiently (Few, 2012; Kirk, 2012).

In an attempt to model the visualisation process in its simplest form, the author has identified and summarised this as three key stages; acquisition, processing and visualisation, shown in Figure 1.



Figure 1: Typical data visualisation process

In the following sub-sections, each of these stages will be briefly introduced, with focus on how they can form the process of gathering and preparing subsea survey data for effective visualisation.

3.1 Acquisition

Acquisition involves the collection or generation of subsea survey data. This is a complex and technical process, usually undertaken by hydrographic surveyors, and requires the combination of a variety of equipment and software in addition to using sonar equipment.

ADUS DeepOcean “has found that the best high frequency multi-beam systems give the best results – provided they are coupled to the best motion reference units and positioning systems” (Dean et al., 2010), with their equipment choices reflecting this approach. Over 50 factors have also been identified which affect multi-beam sonar survey quality, and these are both considered and addressed during the data gathering process.

To begin acquisition, a suitable vessel must be available, and the equipment must then be ‘mobilised’. Surveys by ADUS DeepOcean generally involve the use of a multi-beam sonar system, such as a Reson 7125 SV2, alongside an inertial navigation system, consisting of both RTK (Real-Time Kinematic) GPS and a motion reference unit, typically an Applanix POS MV 320. A sound velocity profiler is also used, and this enables correction of the multi-beam data by measuring differences in the speed of sound at varying water depths.

3.2 Processing

Although some processing happens alongside acquisition (such as applying real-time GPS corrections), the bulk of processing happens once the gathering of data is complete.

The first stage of processing is to ensure that any corrections have been applied, such as GPS corrections, or those from the motion reference unit. Once the data has been corrected, it is ready for cleaning, where any unwanted or ‘bad’ data is removed – this usually involves removing any data points which are unnecessary and overcomplicate the resulting dataset (often referred to as noise). A large proportion of cleaning subsea survey data is still a manual process - requiring time, patience, and someone with skill and experience of working with this type of data. These corrected and cleaned datasets are then ready for visualisation.

3.3 Visualisation

The visualisation stage consists of several sub-steps, and in the ADUS DeepOcean process, is usually undertaken by a team of experienced visual researchers.

Visualising the processed and cleaned data can be undertaken in a variety of ways, depending upon the requirements of the client and the deliverables they desire. This will typically include the segmentation of

datasets to simplify viewing, and the addition of colour, which improves clarity in the presentation of the data. It may also involve providing measurements of objects, or creating comparisons of structures. Delivery of the final datasets is also carefully considered, as some clients have a preference - perhaps requesting that two-dimensional charts are produced from the survey data.

4 BEYOND THE SCREEN

Despite significant advances in the delivery and presentation of data visualisation, the methods used to communicate and display subsea survey data remain somewhat limited. For example, on a large-scale commercial project in 2014, ADUS DeepOcean surveyed an offshore wind farm of approximately 140 turbines, delivering a series of two-dimensional charts that used the more traditional or scientific ‘rainbow-ramp’ colouring - an example of which is shown in Figure 2.

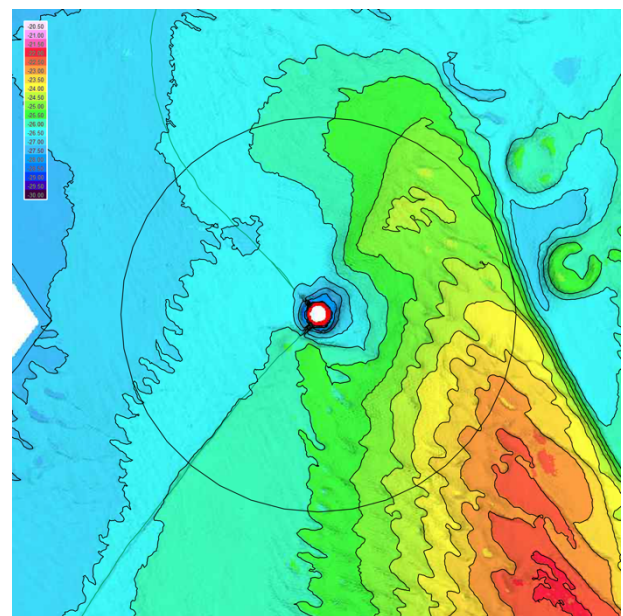


Figure 2: Resulting survey image, provided by ADUS DeepOcean

It is suspected that these deliverables represent the type of documents that the client was in the habit of working with, having no interest in viewing their data differently.

This example introduces two main problems. The first is that presenting three physical dimensions in a two-dimensional ‘flat’ format does not convey the truest sense of the data. Tufte (2001) states that for graphical excellence, “the number of information-carrying (variable) dimensions should not exceed the number of dimensions in the data”. Similarly, if we consider the inverse of this (using the example in

Figure 2), three dimensions of data are presented using two-dimensional charts – there are not enough spatial dimensions for all of the data being displayed, with the third (Z, or depth) being represented using colour – our second problem, with research showing that the ‘rainbow-ramp’ approach to colour has proven highly ineffective, as the brain cannot naturally order these colours (Tufte, 1990; Rogowitz and Treinish, 1995; Ware, 2000; Borland and Taylor, 2007).

By viewing three-dimensional data in three suitable dimensions (maximising the use of information-carrying variables), users can still explore, measure and make decisions, and research suggests that through good visualisation, the understanding of data can be both quickened and increased (Kirk, 2012; Few, 2013; Yau, 2013).

Roberts et al. (2014) also believe that “mapping data to an appropriate visual form is a key to creating useful visualizations”, with more recent developments involving the inclusion of time, interactivity or sound, or making use of newer technologies such as stereoscopic rendering or 3D printing – that is, beginning to look ‘beyond the screen’.

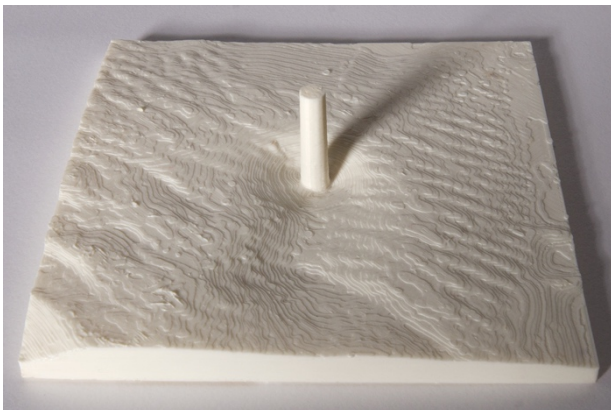


Figure 3: Example of a 3D print, created from multi-beam survey data

As one of the most exciting developments, 3D printing now allows for the fabrication of three-dimensional physical objects from a digital model. An example of this can be seen in Figure 3, which shows an area of seabed (measuring 100x100m) surrounding the base of an offshore wind turbine, based on data gathered using multi-beam sonar. Interestingly, the process of ‘building’ this through additive layering creates a similar effect to the familiar contour mapping already used in survey charts (seen in Figure 2).

Gwilt et al. (2012) believe that “the creation of a physical object based on a digital data set is in a sense a new ‘complex’ media form”, and conducted

a series of pilot studies to explore the creation of data-informed objects and if they could improve cognition of the underlying data. They found that the data-objects easily stimulated discussion, although some were too abstracted from the data to have any easily gained meaning. However, with careful consideration of material, shape, texture and so on, it is believed that data-objects offer an “extended visual language” which can “potentially broaden the community of understanding” (Gwilt et al., 2012).

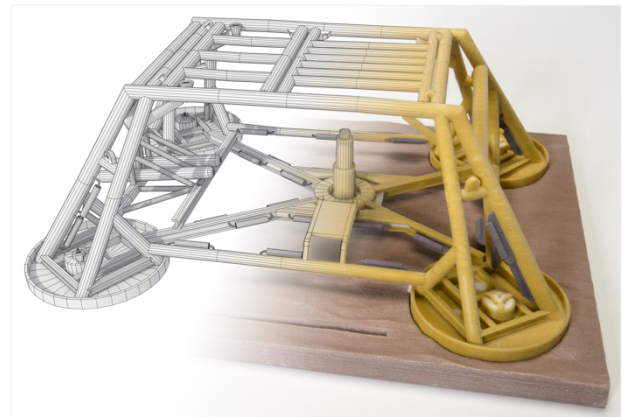


Figure 4: A digital surface model alongside its 3D printed physical representation

In addition to this, the use of 3D printing techniques allows for data to be presented to more than one sense, with multi-sensory visualisations referred to as “the next big thing” by Roberts et al. (2014).

If we consider explorable dimensions of subsea survey data (usually four in total - X, Y, Z, and time), viewing an on-screen visualisation can present all four of these dimensions simultaneously, typically to a single sense – sight. In contrast, viewing a 3D printed visualisation can present the same four dimensions, but this time taking advantage of two senses – sight, and touch (with a change over time displayed using multiple printed models). It is for this reason that tangible data can offer a richer experience, provided that we continue to adhere to the principles of “graphic excellence” (Tufte, 2001), and consideration is given to not exploiting the senses of the viewer unnecessarily, as this can “lead to sensory and cognitive overload” (Roberts et al., 2014). Despite being a relatively new area of research with little understanding as to the reasons why, physical visualisation methods seem to offer increased engagement with and better understanding of data (Gwilt et al., 2012).

However, despite the advantages of multi-sensory visualisation through 3D printing, the author has identified that subsea survey companies have not yet readily adopted this as an updated and useable solution over current methods - although there is no clear explanation for this. Perhaps these companies

do not 'understand' the new formats, or see no reason to change. It may also be that they have not yet been presented with good quality 3D printed visualisations that would let them see the benefits of the process.

5 WORKSHOP STUDY – “T-E4E5”

To try and understand their reasons better, the author conducted a series of interactive workshops (or focus groups) on identifying and comparing the communicative value of different visualisation techniques against one another, using subsea survey data as the basis for this.

Creation and delivery of these workshops was undertaken using a multi-method approach. A design research methodology was used – an approach which encourages practice-based learning, where “acts of making and reflection can occur along the entire length of the process” (Sanders and Stappers, 2014). This is similar in nature to an action research methodology (McKernan, 1996), which perhaps fits better within the arts, and resulted in a cyclic or iterative process of improvement.

With the author also adopting the role of the reflective practitioner (Schön, 1991), this triangulated approach is of particular importance as it encourages reflection and iteration during all stages of the design and research processes, rather than just an analysis or evaluation of a finished product or experiment. This methodological approach created more opportunities for knowledge and learning to be extracted and then applied, improving both the process and the product – in this case, the workshop and its outcomes.

These workshop sessions captured both quantitative and qualitative (multi-dimensional) data, which would prove useful in determining the value, if any, added to or removed from the data when using both current and new visualisation methods.

The same dataset was used throughout, referred to as “T-E4E5”, which was a survey of a protective structure (protecting a wellhead used for drilling oil), located in the North Sea at a depth of approximately 325m. This data was captured using multi-beam sonar, from a series of fixed positions, and then ‘stitched’ together.

Workshop participants were presented with eight key stages of visualisation development, starting with the raw numerical data (as captured by multi-beam sonar) and ending with a physical 3D print of the structure. These eight stages can be seen in Figure 5.

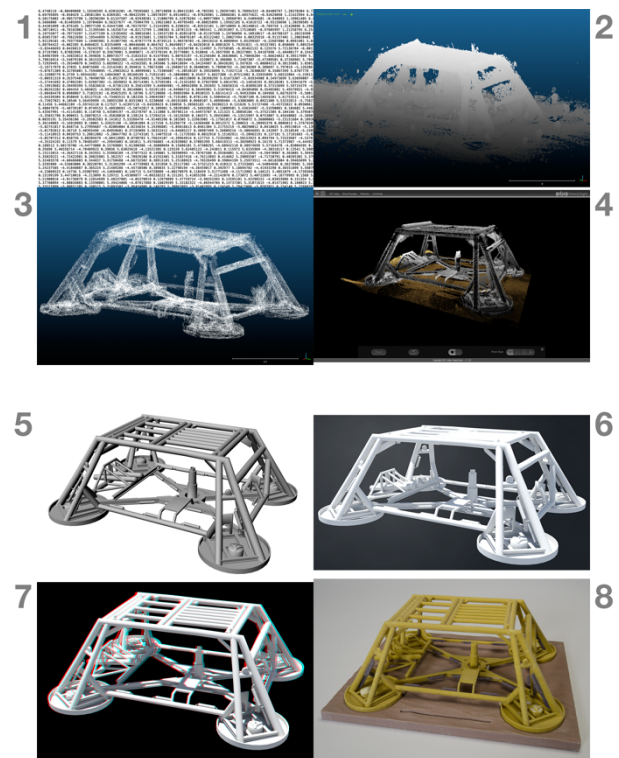


Figure 5 - Eight key stages of the T-E4E5 data visualisation lifecycle

Stages 1 through 4 represent the typical steps that result in the deliverables that ADUS DeepOcean would provide a client. In order - raw numerical data, point cloud data, processed (cleaned and subsampled) point cloud data, and an interactive 3D point cloud presented in ADUS DeepOcean's own WreckSight visualisation application, which can be used to measure accurately.

Stages 5 through 8 show further development beyond the current deliverables – surface model, rendered surface model, anaglyph stereoscopic and finally, a 3D printed physical model. It is important to note that for stage 7, suitable glasses were provided for viewing, and for stage 8, the 3D print was present throughout the process.

Participants were briefed on what each of these stages represented, and were asked to place a 'sticky-note' as their vote on how well each stage communicated the underlying data. There were four categories - Unclear, Understandable, Interesting and Exciting – which were chosen as more natural 'human' responses to visualisation, rather than numerical choices.

Multi-dimensional data was captured, as although participants voted along a spectrum of fixed options (providing quantitative data for direct comparison of methods), they could also write any thoughts that they may have had onto the sticky-note (providing qualitative data for deeper analysis and

understanding). Figure 6 is an example taken from one of these completed workshops, showing both the grading scale and the way in which participants provided their responses.

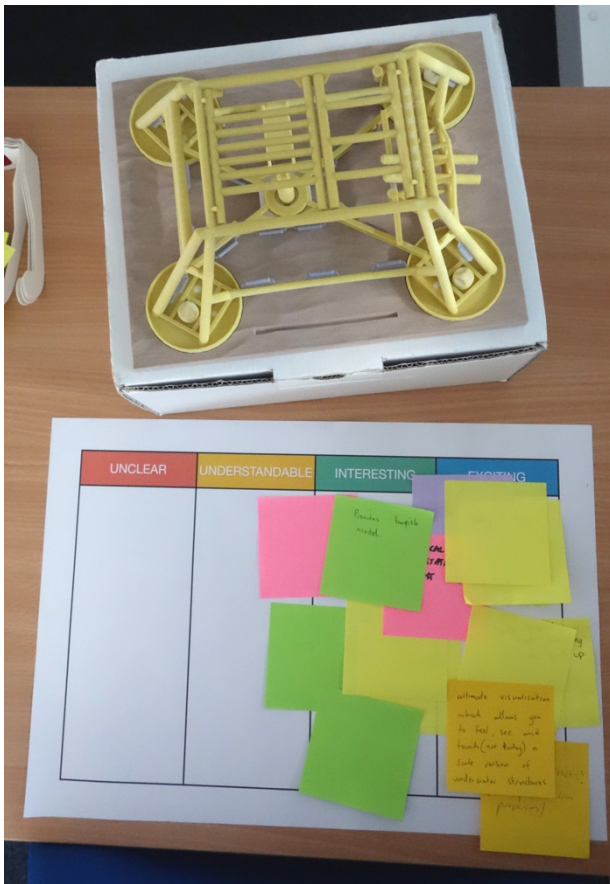


Figure 6: Example of results gathered during workshops

6 WORKSHOP REFLECTION

After compiling the results of these four workshops some early thoughts are provided, based on the resulting data that has been gathered, collated and visualised – shown in Figure 7.

If we first consider the number of responses (around 60 participants in total) – not all of the visualisation stages received an equal number of votes, suggesting that participants either voted for some twice, or chose not to grade particular stages. Of particular interest is that stages 5 and 6 received around 10% less votes than the average, and stages 7 and 8 received approximately 10% more than the average number of votes. This trend implies that the creation of surface models was of less interest than the use of stereoscopic or 3D printing as visualisation methods. This difference in participant volume is also evident in their grading of the understanding, interest and excitement in each of these stages.

A significant increase in understanding the data was achieved by stage 3, where the data has undergone some processing – with around 90% of participants showing understanding. There is no further notable increase in basic understanding levels beyond this.

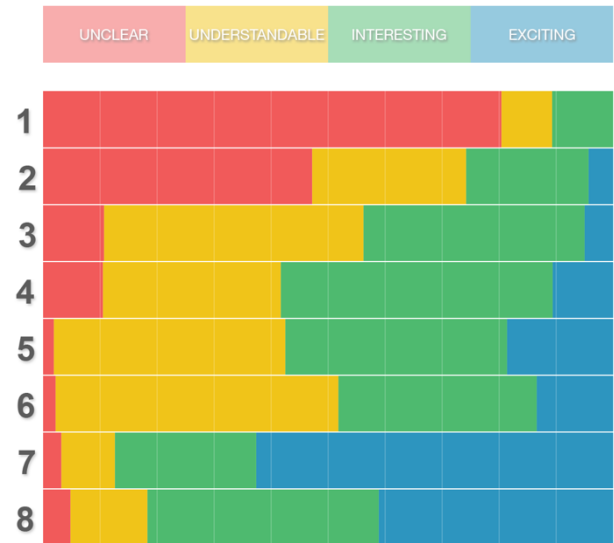


Figure 7: Collected results from four workshops

However, combined levels of interest and excitement generated by the data appear to have increased gradually until stage 4, where approximately 68% of participants found the data more than understandable. This then falls to 48% as stage 6 is reached, and jumps up again significantly for stages 7 (88%) and 8 (82%), suggesting that although basic understanding is not increased using these emerging visualisation methods, both interest and excitement are – this can lead to greater engagement, and an increased amount of discussion around the dataset, as was evident during the course of these workshops.

Based on the outcome of these trial workshops, there is a clear argument for the use of new methods such as stereoscopic or 3D printing over on-screen methods of visualising subsea survey data, particularly when looking at increasing user engagement, and comparing the communicative value of each different stage in the 'data lifecycle'. In this instance, there is a preference towards 3D printing, rather than using stereoscopic imagery, as it does not require any specialist equipment to view.

However, as this was a limited set of responses relating to a single dataset, there should be a further study to verify these results. This will broaden the range of responses being gathered, allowing additional datasets to be included for more reliable results.

7 CONCLUSION

Subsea survey data is three-dimensional in nature, and represents physical, real-world objects. By relying on older methods that are not intended to convey an equivalent number of dimensions, the data effectively becomes restricted, and limits our ability to interact with and interrogate the rich data being gathered.

However, as visualisation techniques are rapidly being developed and progressed, adoption of these new ways of presenting data remains slow when considering subsea survey data – clients are still asking for deliverables that do not appear to be taking advantage of recent advancements in technology, for example 3D printing, or new research, such as the already-mentioned developments in graphical excellence (Tufte, 2001), colour theory (Borland and Taylor, 2007), multi-sensory visualisation (Roberts et al., 2014) and tangible data (Gwilt et al., 2012).

Having started to apply these new techniques to survey data (beyond the typical client deliverables) and undertaken a series of workshops to test the communicative value of each of the visualisation stages, the author has identified an improvement in the communication of subsea data using 3D printing, and hopes to further our understanding of how we can continue to improve interaction with this type of data, and improve engagement in those wishing to explore it further.

In addition, it is also suggested that the approach needed to develop the visualisation of subsea survey data will be multi-faceted in nature, relying on a combination of informed choices, rather than changing only one feature or attribute (for example, changing output medium is simply not enough).

Alternatively, the slower uptake of 3D printing in visualising subsea survey data may be solely due to the fact that it is 'new', and that the end result is not yet of a suitable quality to be useful. Tufte (2001) told us that "graphics reveal data" – working within a team of established visual researchers, if the visualisation process has been proven to reliably achieve good results, and the results are not useful, then it suggests that the initial data being visualised may not be of a good enough quality for 3D printing.

This identifies a new problem for future research and development, as the 'data out' can only be as good as the 'data in' - if there is not good data, it cannot result in good *tangible* data. However, when it comes to defining 'good' and 'bad' data, this remains largely subjective, and developing a way of measuring this will prove essential in identifying ways of improving 'data in', and in turn also improving 'data out', leading to better results in creating multi-sensory tangible data as an effective visualisation tool.

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